Recent results from the Telescope Array experiment

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Outline

- Telescope Array(TA) Detectors
- Recent preliminary TA results
  - Energy spectrum
  - Mass composition
  - Anisotropy
- Summary

Telescope Array Collaboration

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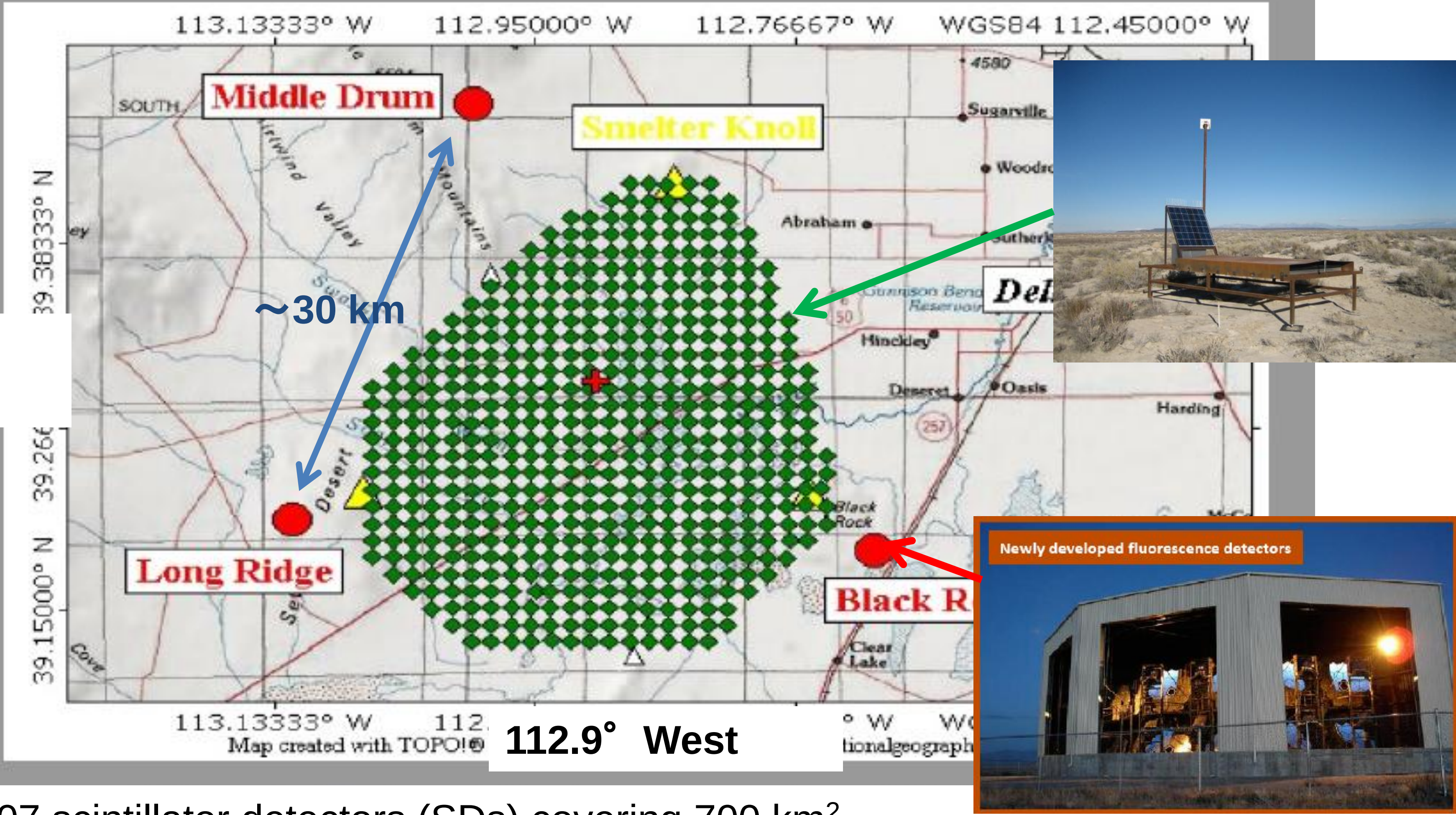
K. Yashiro[e], Y. Yoneda[j], S. Yoshida[s], H. Yoshii[ad], R. Zollinger[a], Z. Zundel[a]

~120 collaborators in 5 countries

Japan, USA, Korea, Russia, Belgium

[a]University of Utah, [b]Tokyo Institute of Technology, [c]Ewha Womans University, [d]Hanyang University, [e]Tokyo University of Science, [f]Kinki University, [g]Yonsei University, [h]Institute for Cosmic Ray Research, Univ. of Tokyo, [i]Kavli Institute for the Physics and Mathematics of the Universe (WPI), Todai Institutes for Advanced Study, the University of Tokyo, [j]Osaka City University, [k]Kanagawa University, [l]Univ. of Yamanashi, [m]Saitama University, [n]Astrophysical Big Bang Laboratory, RIKEN, [o]Rutgers University, [p]Tokyo City University, [q]Institute for Nuclear Research of the Russian Academy of Sciences, [r]Waseda University, [s]Chiba University, [t]Institute of Particle and Nuclear Studies, KEK, [u]Kochi University, [v]Ritsumeikan University, [w]Sungkyunkwan University, [x]Universite Libre de Bruxelles, [y]Chungnam National University, [z]Earthquake Research Institute, University of Tokyo, [aa]Hiroshima City University, [ab]Advanced Science Institute, RIKEN, [ac]National Institute of Radiological Science, [ad]Ehime University

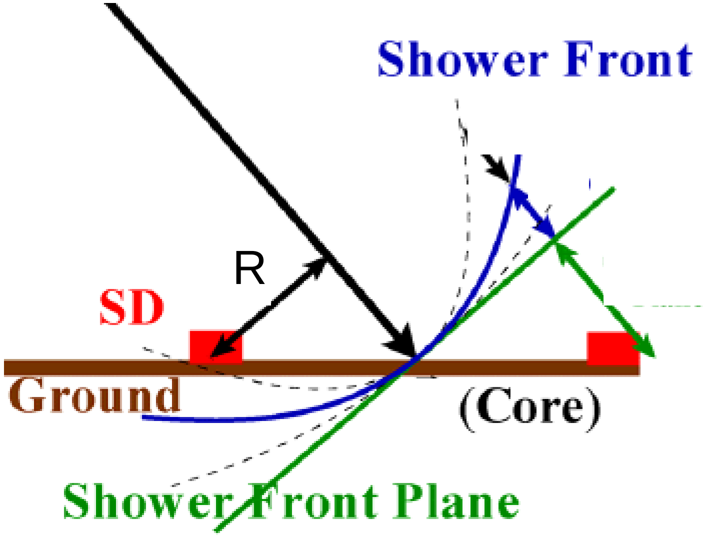
TELESCOPE ARRAY HYBRID DETECTOR



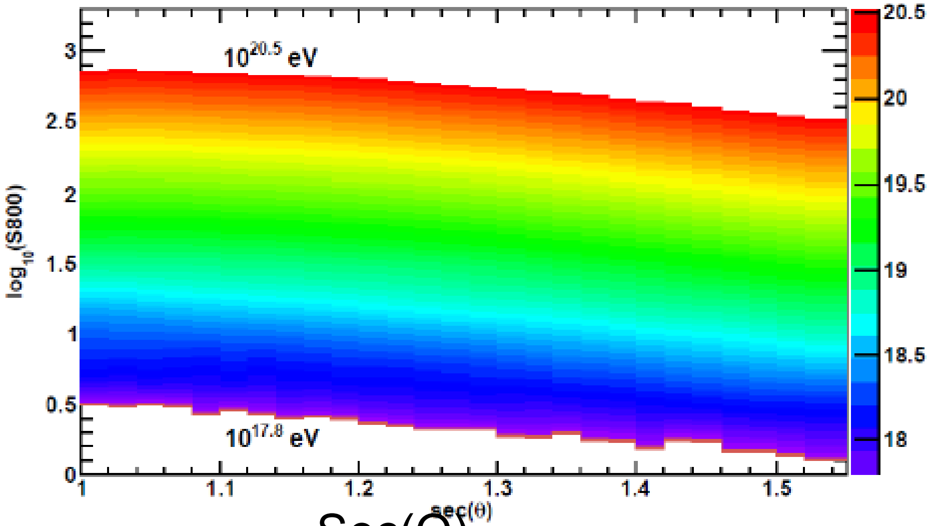
507 scintillator detectors (SDs) covering 700 km^2
3 fluorescence sites, 38 telescopes (∼10% duty cycle)
Surface detector full operation (∼100% duty cycle)
SD & FD Full operation from 11 May 2008
SD relative size:TA∼7 AGASA ∼ PAO/4

Energy spectrum

SD Event Reconstructions



Log10(S(800))

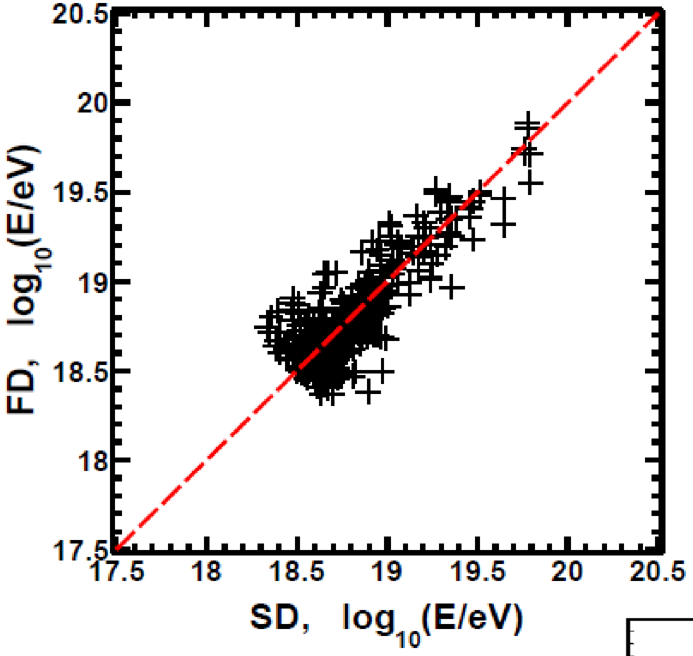


Sec(Θ)

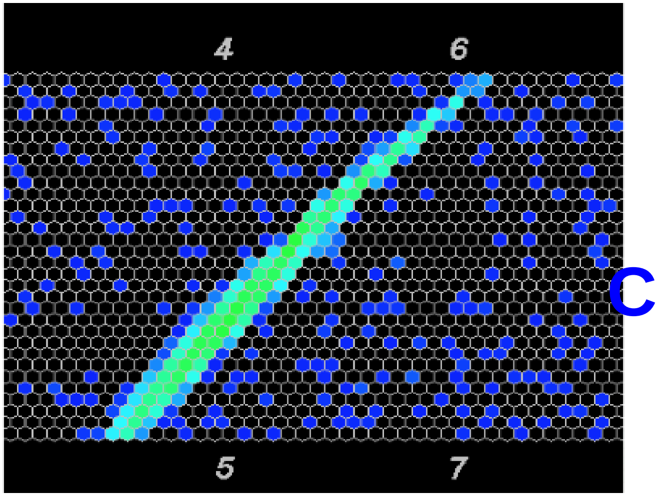
- Timing fit→Shower Geometry
- Lateral distribution fit →S(800)→Energy from MC
- Angular resolution: 1.5° , Energy resolution:20% E> 10^{19} eV

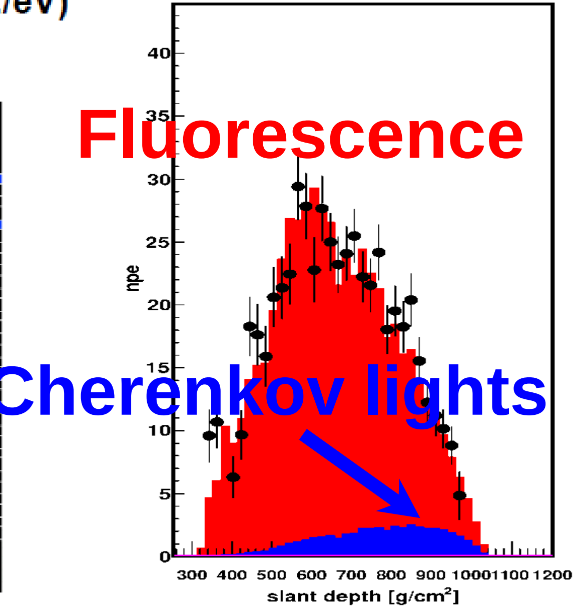
S(800): energy depositions at R=800(m) which are converted in VEM unit.

TA energy scale



- Use E_{FD} energy: calorimetrically determined energy
- Systematic uncertainty of FD energy can be evaluated experimentally.
- Rescale factor of SD energy:1/1.27 from SDFD hybrid events



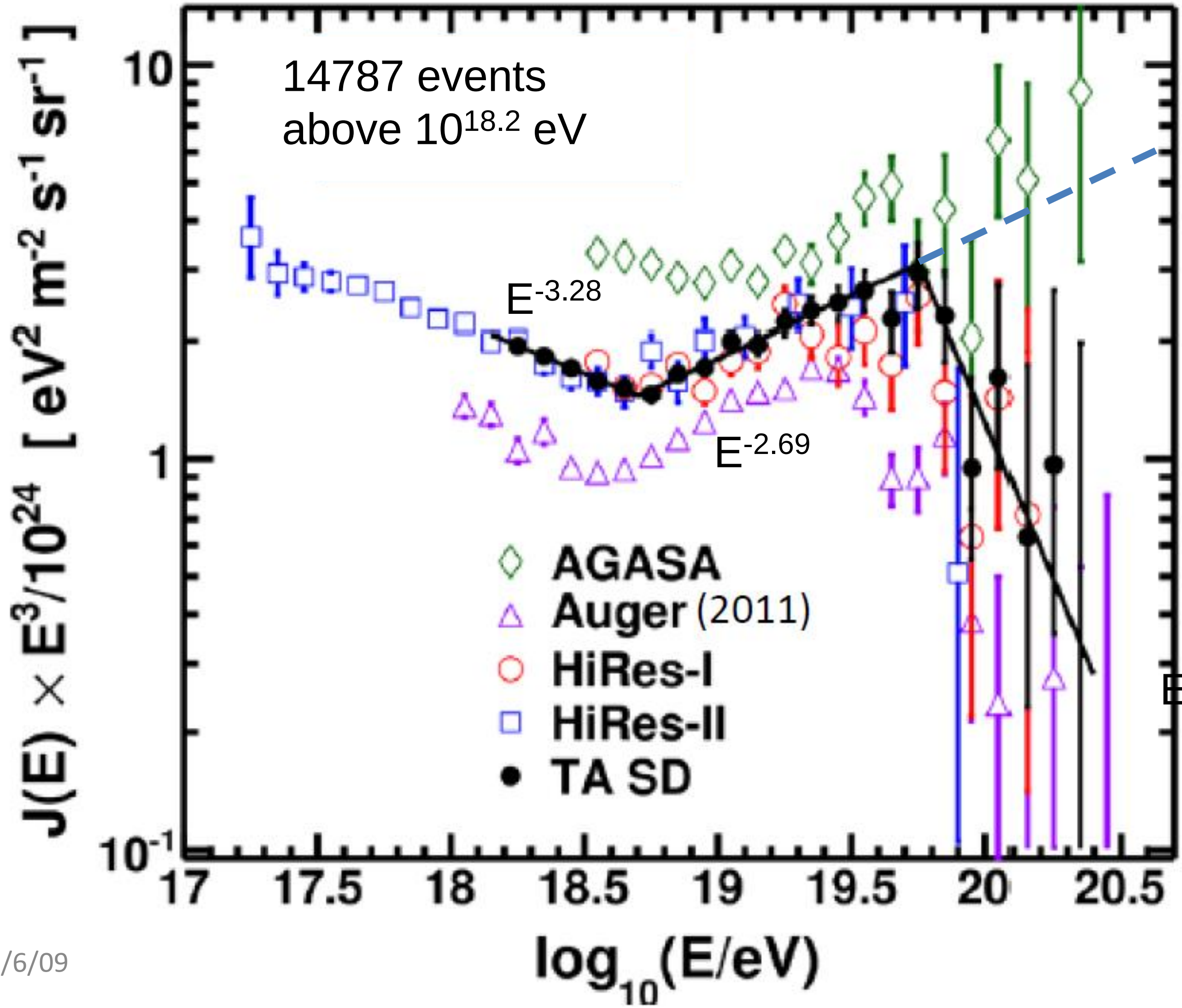


FD energy uncertainty

Source	ΔE/E
Fluorescence yield	11%
Detector	10%
Atmosphere	11%
Reconstruction	10%
Total	21%

5 years TA SD energy spectrum

Updated at ICRC2013
H. Sagawa
D. Bergman



14787 events
above $10^{18.2}$ eV

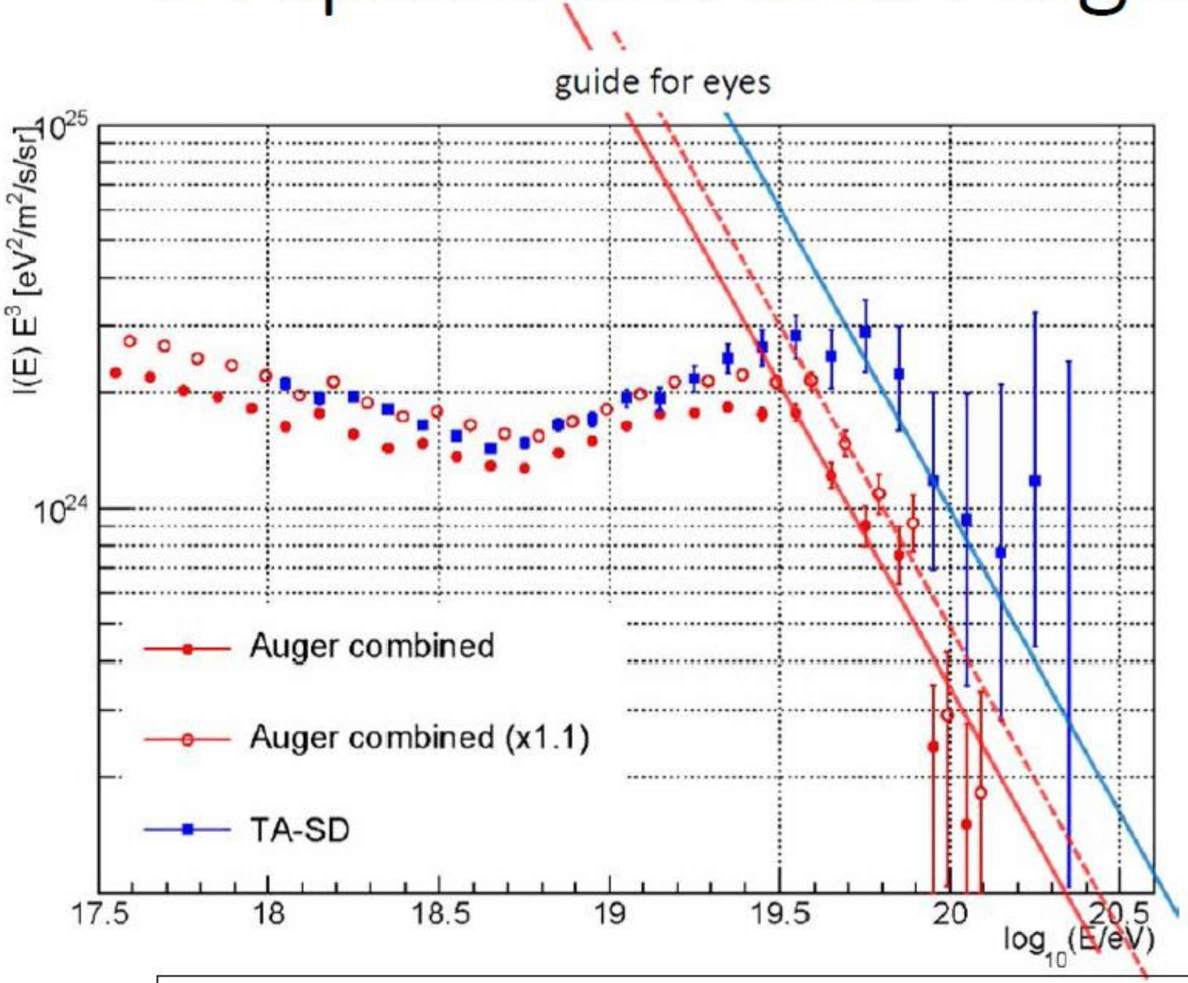
Significance of the event deficit from continuous spectrum for $E > 10^{19.8}$ eV

:$N_{exp} = 68.1$
$N_{data} = 26$
→ **5.7σ**

Broken power law fit

$\gamma_1 = -3.283 \pm 0.032$
$E_{ankle} = (5.04 \pm 0.27) \times 10^{18}$ eV
$\gamma_2 = -2.685 \pm 0.030$
$E_{GZK} = (5.68 \pm 1.05) \times 10^{19}$ eV
$\gamma_3 = -4.62 \pm 0.74$

TA spectrum and Auger spectrum



Rapporteur talk by Y.Tsunesada at ICRC2013

Energy scale uncertainty

. TA: 21%

. Auger: 14%

TA (■) and Auger (Ex1.1) (○)

- shapes agree below$10^{19.4}$ eV
- cutoff positions are different

Fit result with protons from extra-galactic sources

E > $10^{18.2}$ eV(horizon: z〜 0.7)

: **all protons**

4-parameter fit

- Source spectrum: $\mathbf{E^{-p}}$, Emax=10^{21} eV
- Evolution of source density: $\mathbf{(1 + z)^{m}}$
- Flux normalization
- Energy scale

Source distribution

- Uniform
- LSS (~ 2MASS XSCz)

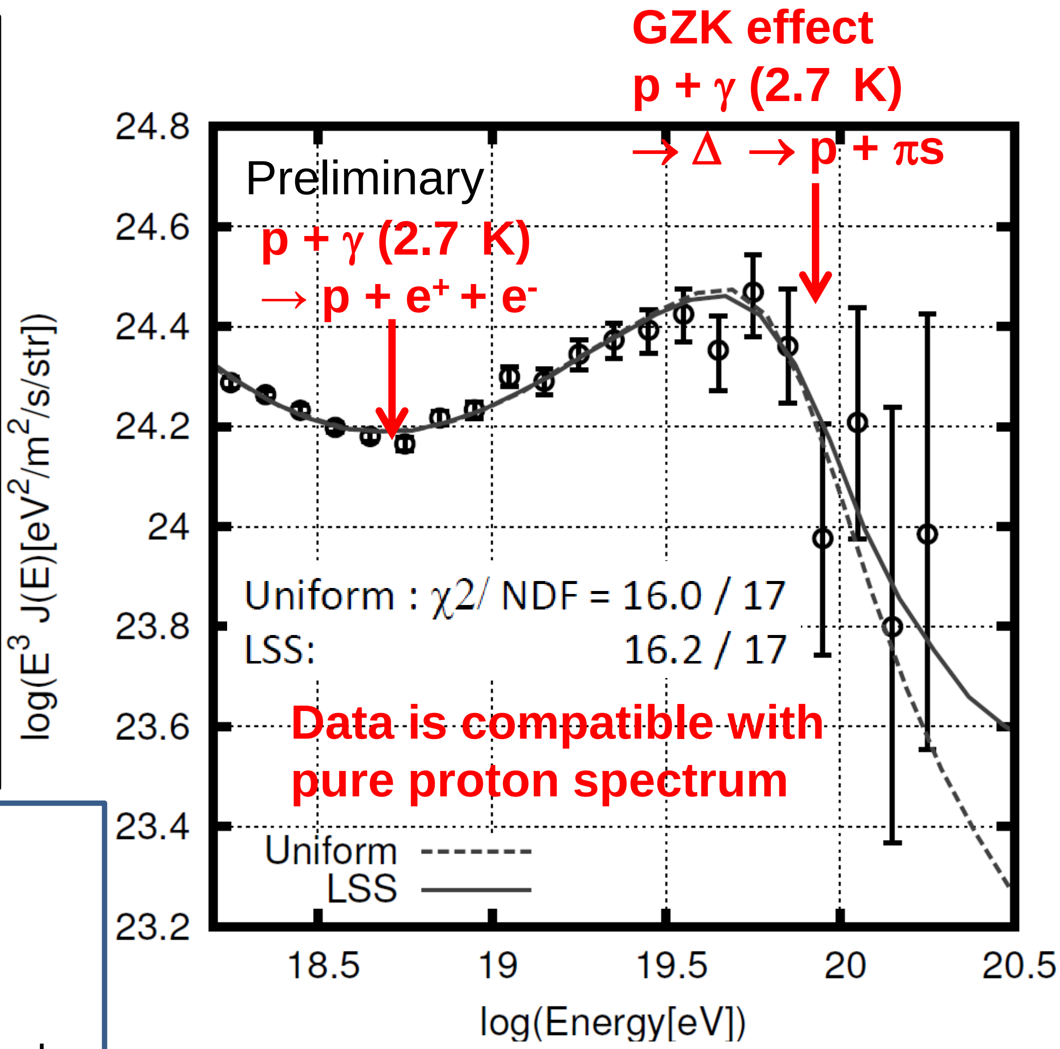
Using CRPropa v2.0.3 (with CMB and IRB)

For LSS, Preliminary fit parameters:

$$p = 2.37^{+0.08}_{-0.08} \quad m = 5.2^{+1.2}_{-1.3}$$

Log E’/E = - 0.02 + 0.04 – 0.05

These will be updated with improved code (arXiv:.1406,0735 [astro-ph.HE])



GZK effect

p + γ (2.7 K) → Δ → p + πs

p + γ (2.7 K) → p + e^+ + e^-

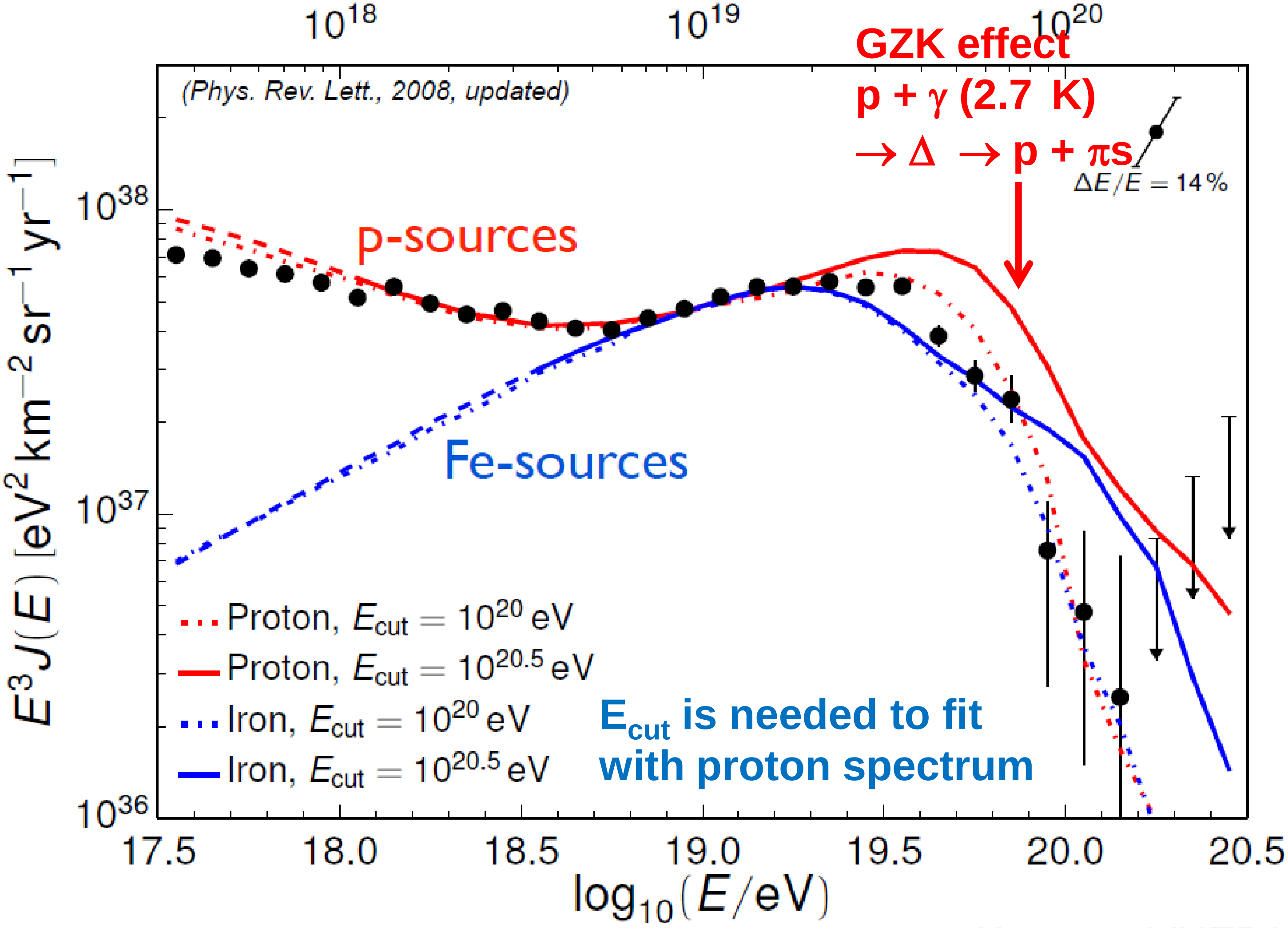
Uniform : χ2/ NDF = 16.0 / 17

LSS: 16.2 / 17

Data is compatible with pure proton spectrum

E.Kido ICRC2013
Preliminary

Auger energy spectrum



GZK effect

$p + \gamma$ (2.7 K)

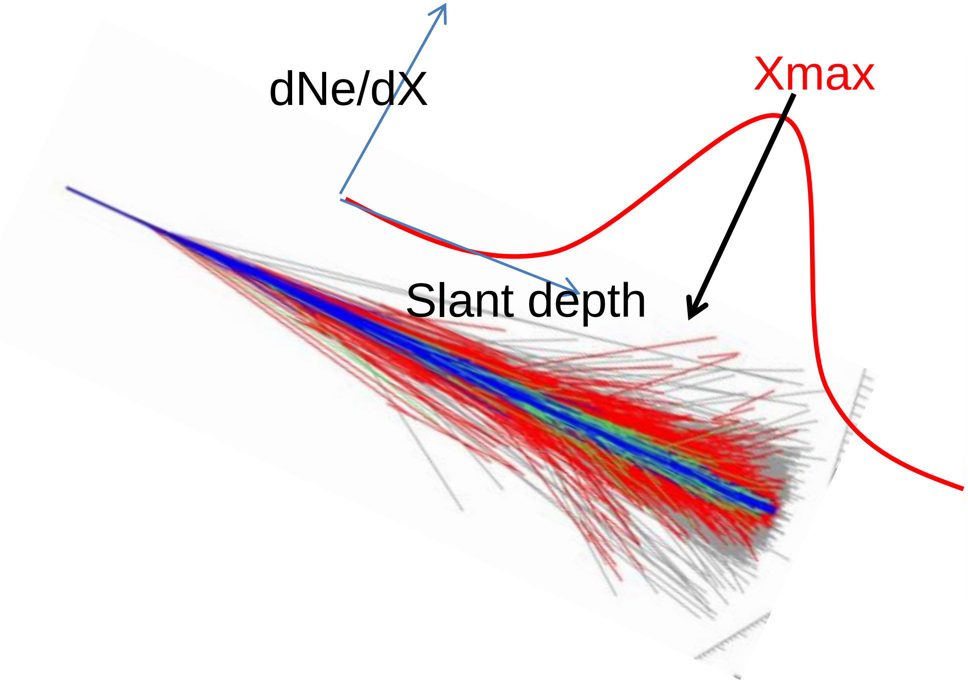
$\rightarrow \Delta \rightarrow p + \pi s$

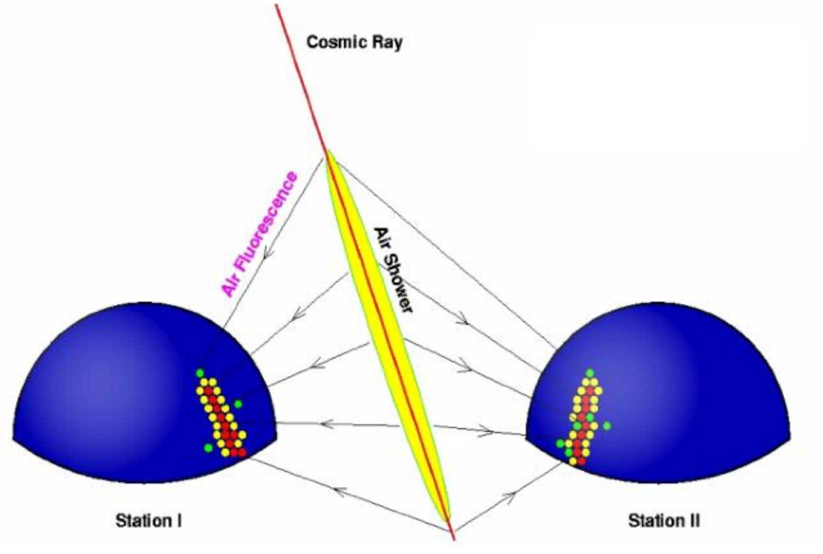
E_{cut} is needed to fit with proton spectrum

Kampert VHEPA (2014)

Mass composition

Xmax measurement by stereo FD





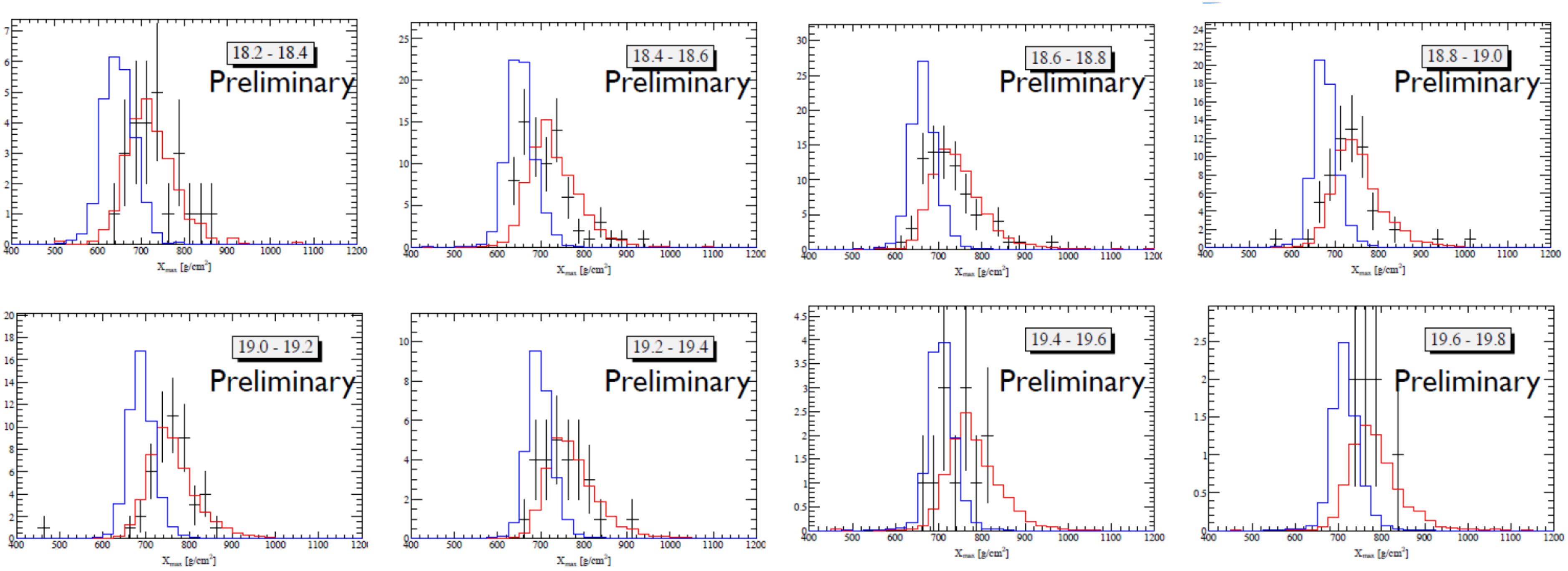
- FD observes shower development directly.
- Xmax is the most efficient parameter for determining primary particle type.

Determination of shower geometry by stereo is much better than mono.
Reconstruction accuracy: 22g/cm^2

Xmax distribution by 5 years stereo FD

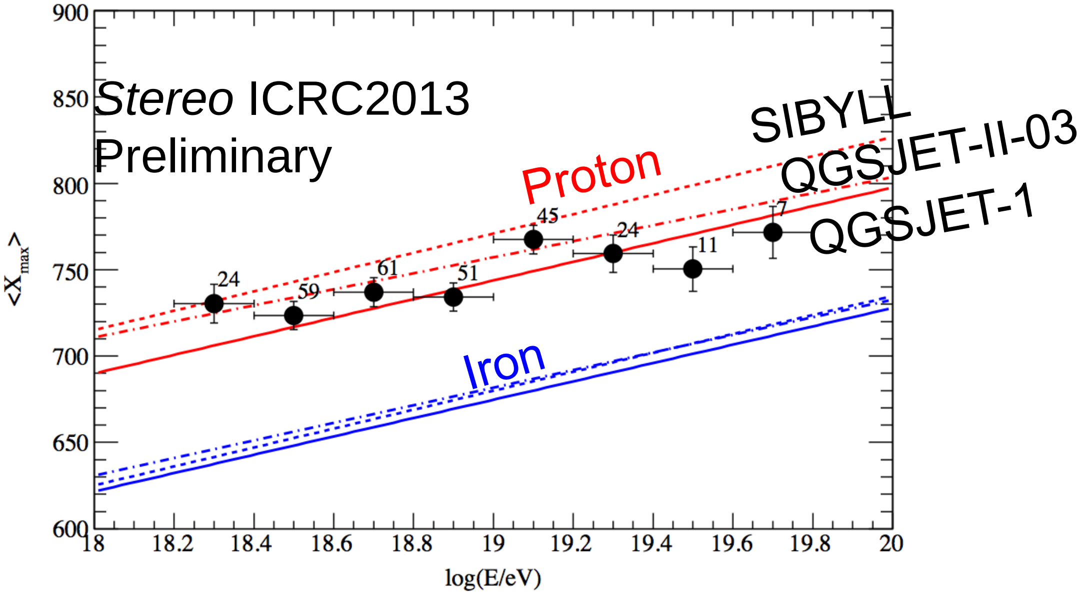
Red: Proton
Blue: Iron

Data:Nov. 2007- Nov. 2011
MC: QGSJET-II-03
Both data and MC with reconstruction bias and cut bias

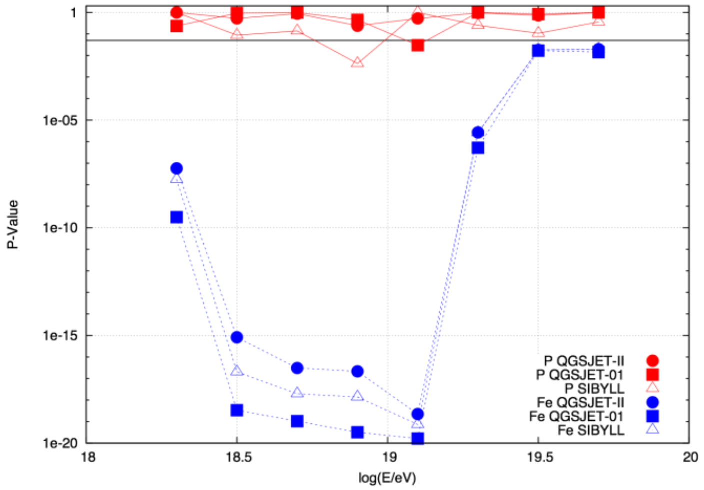


Y. Tameda Preliminary ICRC2013

Xmax distribution by 5 years stereo FD



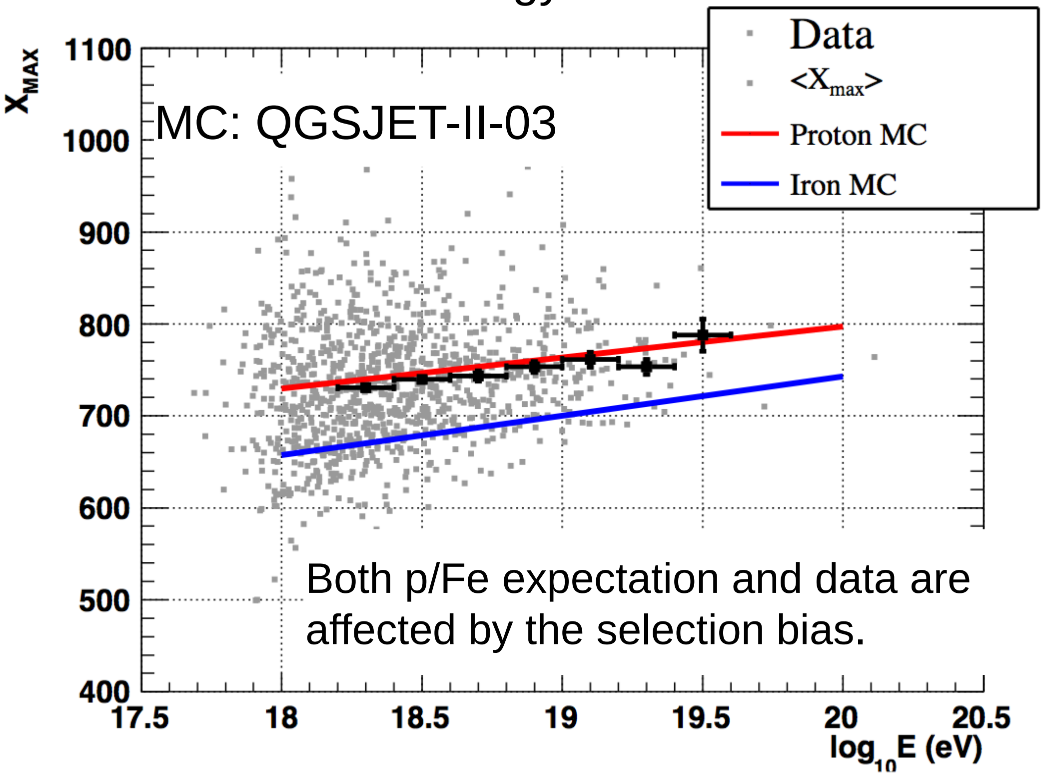
K-S test: proton vs Fe



TA Xmax distribution for E > $10^{18.2}$ eV is consistent with qgsjet-II-03 proton prediction.
We need more data for E > $10^{19.4}$ eV.

Xmax result by SD and FD hybrid

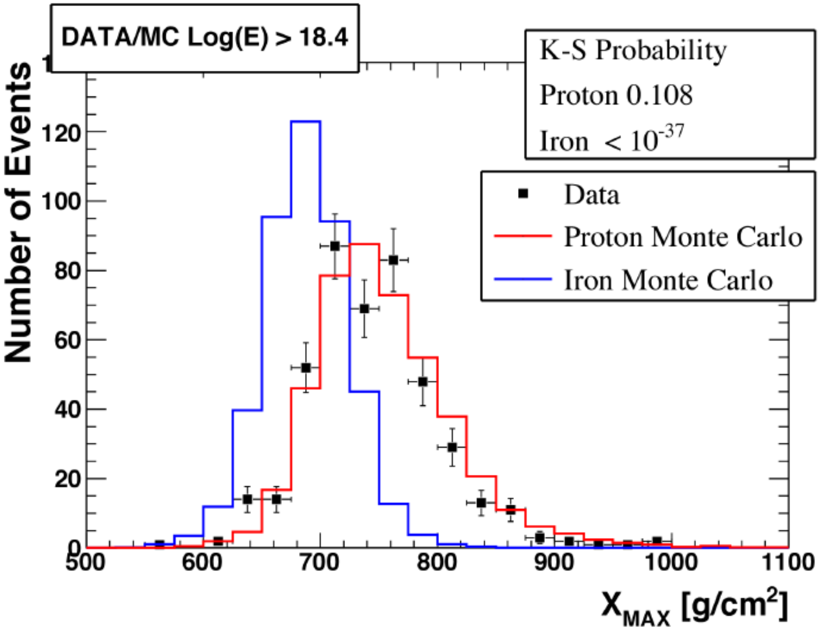
<Xmax> vs Energy



MC: QGSJET-II-03

Both p/Fe expectation and data are affected by the selection bias.

Xmax distribution



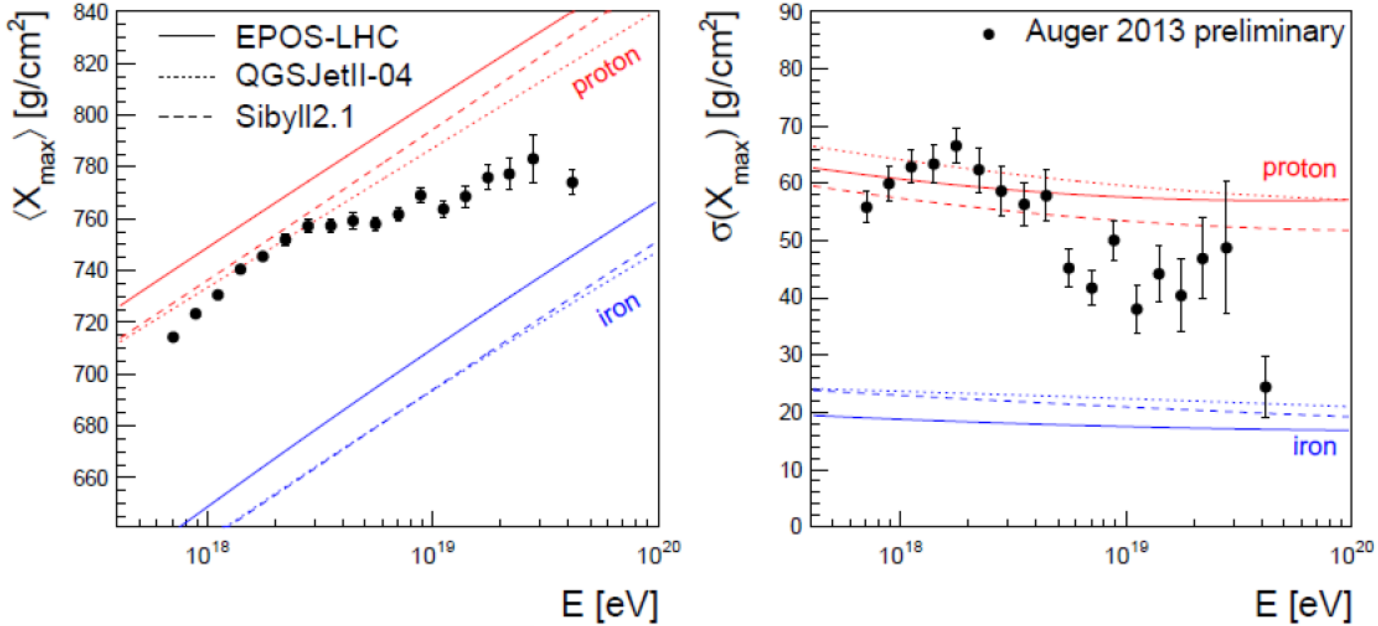
<Xmax> and Xmax distribution for E > $10^{18.2}$ eV is consistent with QGSjet-II-03 proton model by stereo and hybrid analysis

Auger Xmax (updated at ICRC 2013)

- + statistics
- AFY updated.
- PSF updated.
- Calibration etc.

<Xmax> larger
+13 g/cm^2 at 10^{18}eV ~
+6 g/cm^2 at 10$^{19.5}$eV

RMS(Xmax) larger
< 10 g/cm^2
for 10$^{18\text{-}19}$ eV



Updated models: EPOS-LHC and QGSJET-II-04 are used for MC rails.

E.J. Ahn, M. Unger 20
ICRC 2013

Showers at ultra-high energies are shallower and fluctuate less than proton simulations.

Anisotropy

Data set for anisotropy search

- Observation period: 08.05.12- 13.05.04 (5 years) SD data
- Zenith angle up to 55 (deg)
- Geometrical acceptance: exposure ～ 6200 km^2 sr yr
- 2130 events above 10 EeV
- 132 events above 40 EeV
- 52 events above 57 EeV
- Angular resolution: better than 1.5 degree
- Energy resolution: ～20 %

Auto-correlation

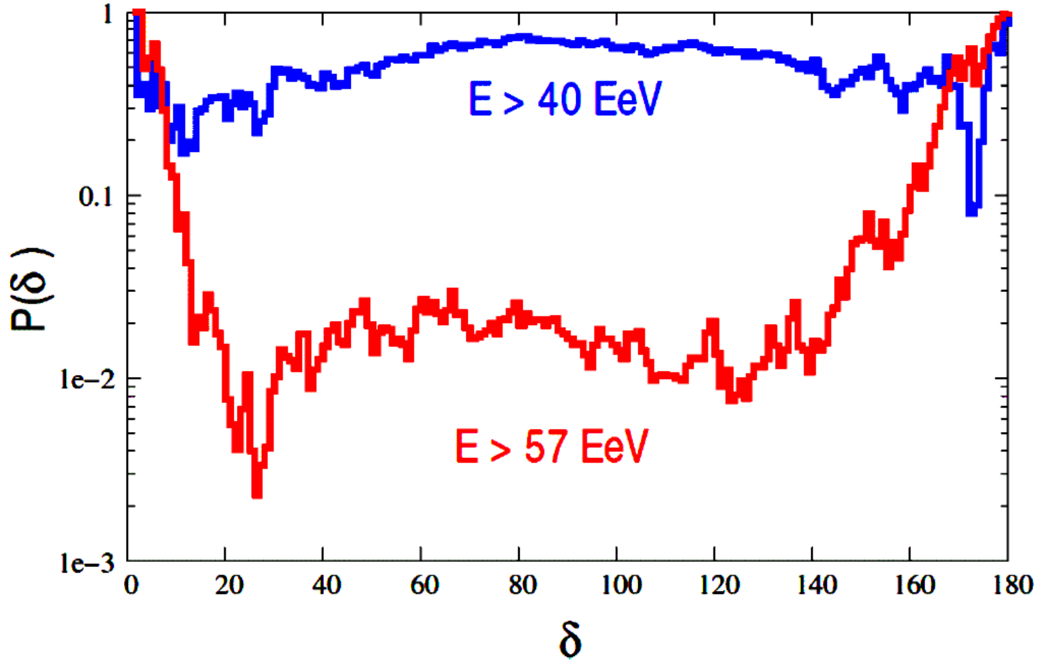
Number of pairs < δ (deg)
is evaluated from isotropy.

Separation Angle:δ

This pair is counted.

This pair is not counted.

Chance probability from isotropy

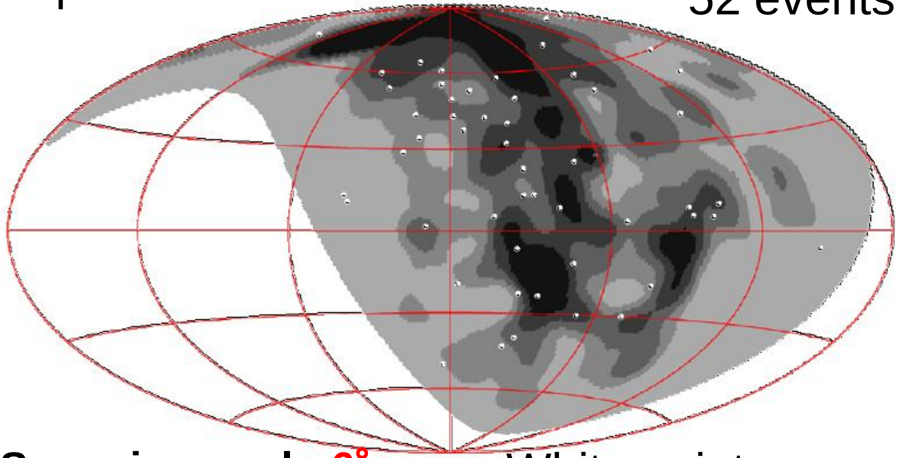


P(δ)∼ 0.004
at δ = 20°
E > 57 EeV, 52 events
Zenith angle < 55°

Correlations with LSS

Shades:
Expected flux

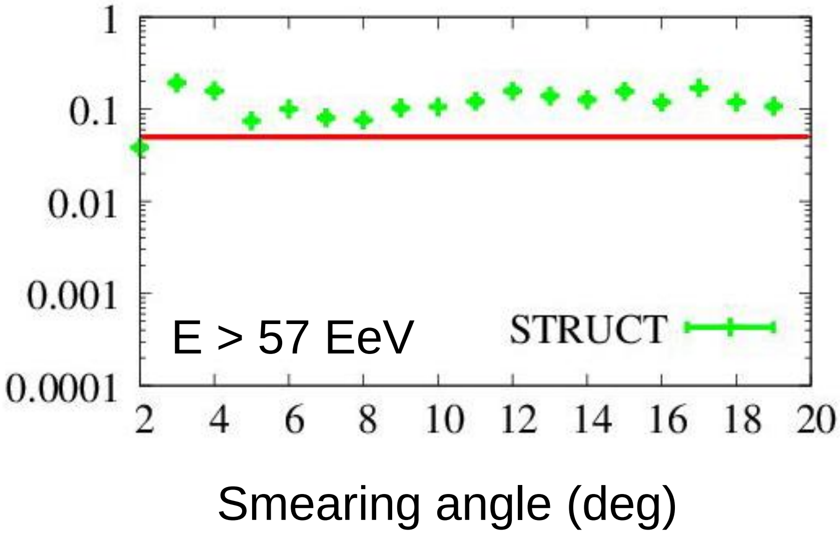
E > 57 EeV
52 events



Smearing angle:6°
Galactic coordinate

White point:
Observed direction

Comparibility with LSS expectation

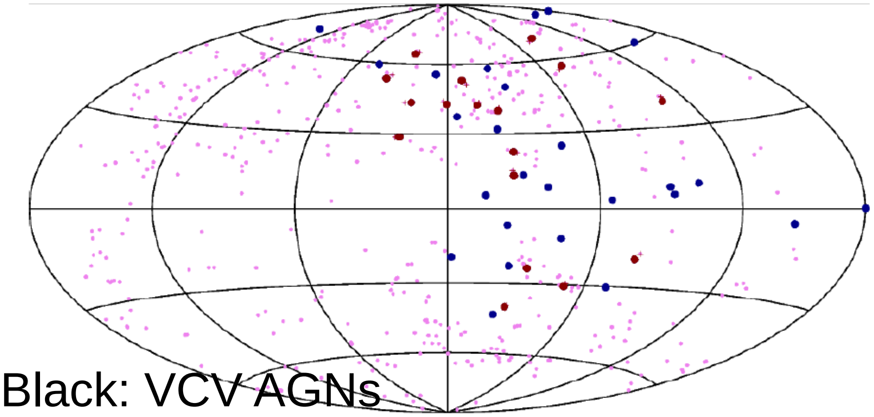


- 2Mass XSCz catalog
- 109000 galaxies, $K_{mag} < 12.5$ within 250 Mpc
- Gaussian smearing of directions
- Protons are assumed.
- Energy loss with CMB considered.

E > 57 EeV
Comparibility with isotropy:
p ∼ 0.001 for 6° smearing

Cross-Correlations with VCV AGNs

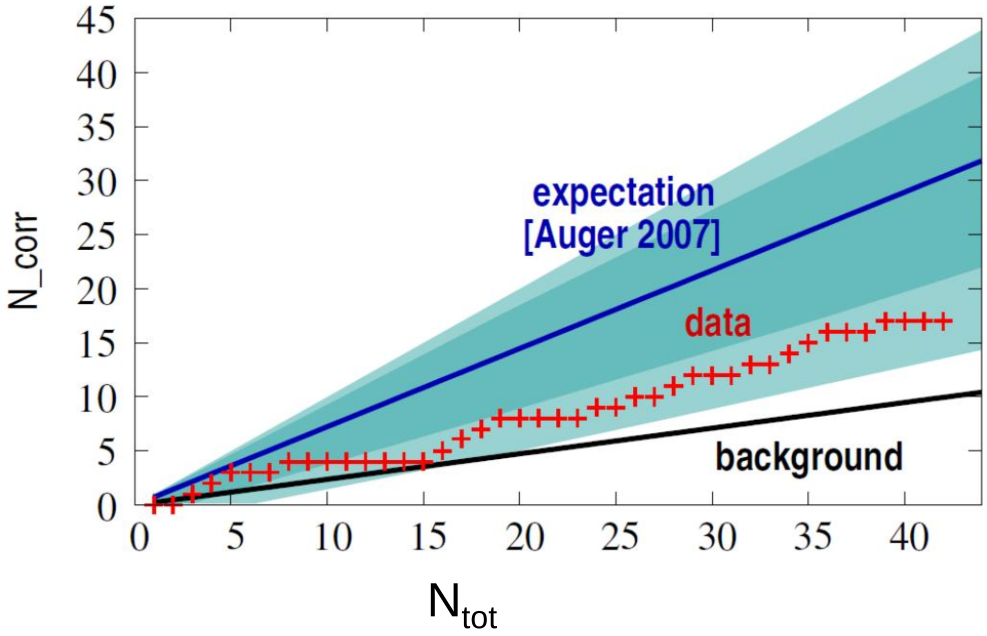
Galactic coordinates



Black: VCV AGNs

Red: correlated events

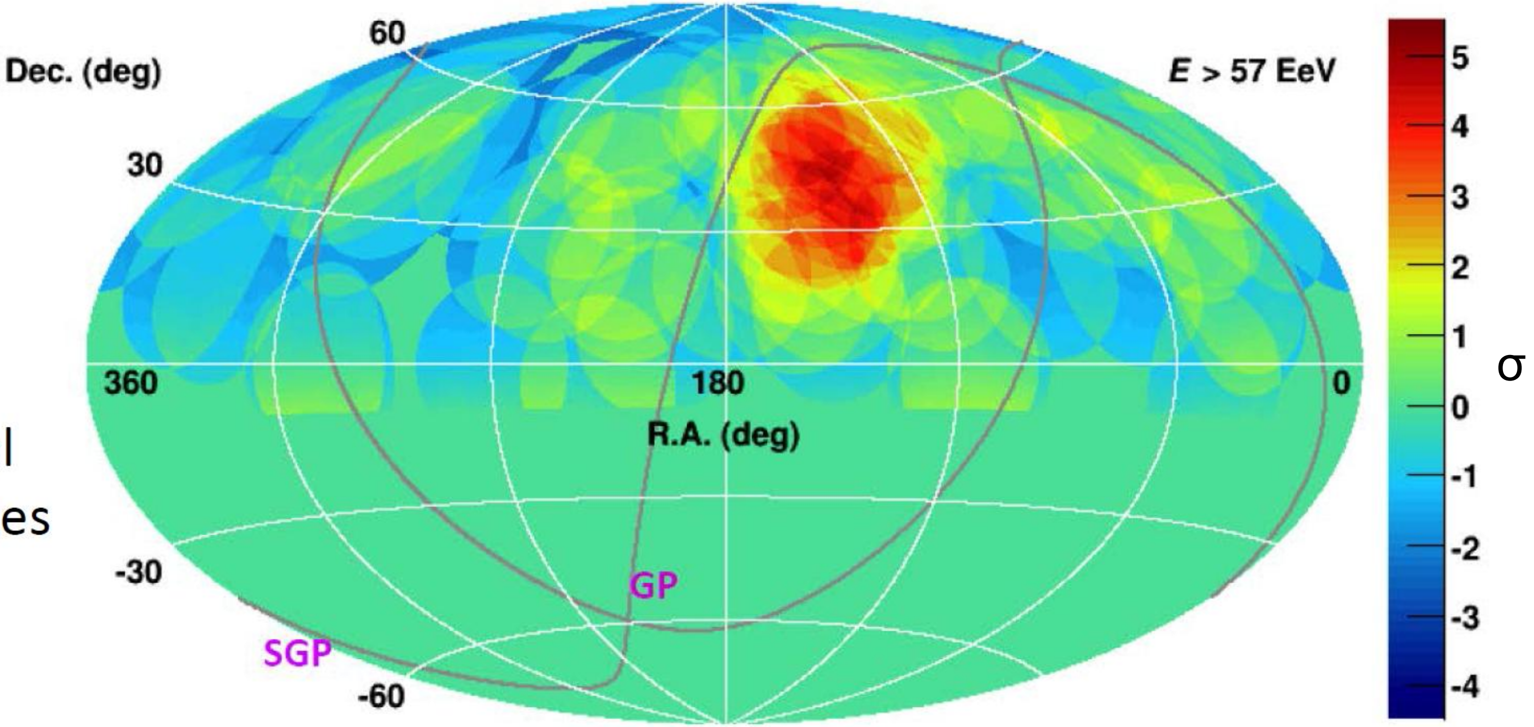
Blue: non-correlated events



- Same catalog (VCV) and same parameters (3.1° angular scale , z ≦ 0.018, E > 57 EeV) are used as Pierre Auger.
- **17** events are correlated with nearby AGNs out of **42** events, while **9.9** events are expected from random coincidences.
  →**chance probability: 1.4 %**
- **17**events/**42** events TA ⇔ **28** events/**84** events latest Auger

Anisotropy indicated with loose cut data

Significance from isotropy



Equatorial coordinates

No border cut and loose quality cuts → 72 events E > 57 EeV

Oversampling with 20 degree radius → Max significance: 5.1σ from isotropy

Chance probability = 0.00014 (3.6σ): 5.1σ significance is found in this probability somewhere in the sky assuming isotropic cosmic-rays.

arXiv: 1404.5890 [astro-ph.HE]

Summary and future prospect

Energy spectrum is **consistent** with **proton model**.

Xmax is **consistent** with **proton model**.

Intermediate 20° scale anisotropy is indicated

in **3.6σ C.L.** at highest energies (E > 57 EeV).

This feature is showing up

in some tests as incompatibility with isotropy.

- Distribution in SuperGalctic declination: p～0.003
- Autocorrelation function p～0.004 at δ=20°
- Correlation with LSS p～0.001 for smearing 6°

→ This feature(Bright source? LSS?) should be tested with a few times larger statistics. and energy spectrum at highest energies

→ TA extension plan (TAx4)

TA × 4 proposal

Extend the coverage of TA surface array to about 3000 km^2

(4 times larger coverage than TA).

500 SDs with 2.08 km array spacing.

(Japan)

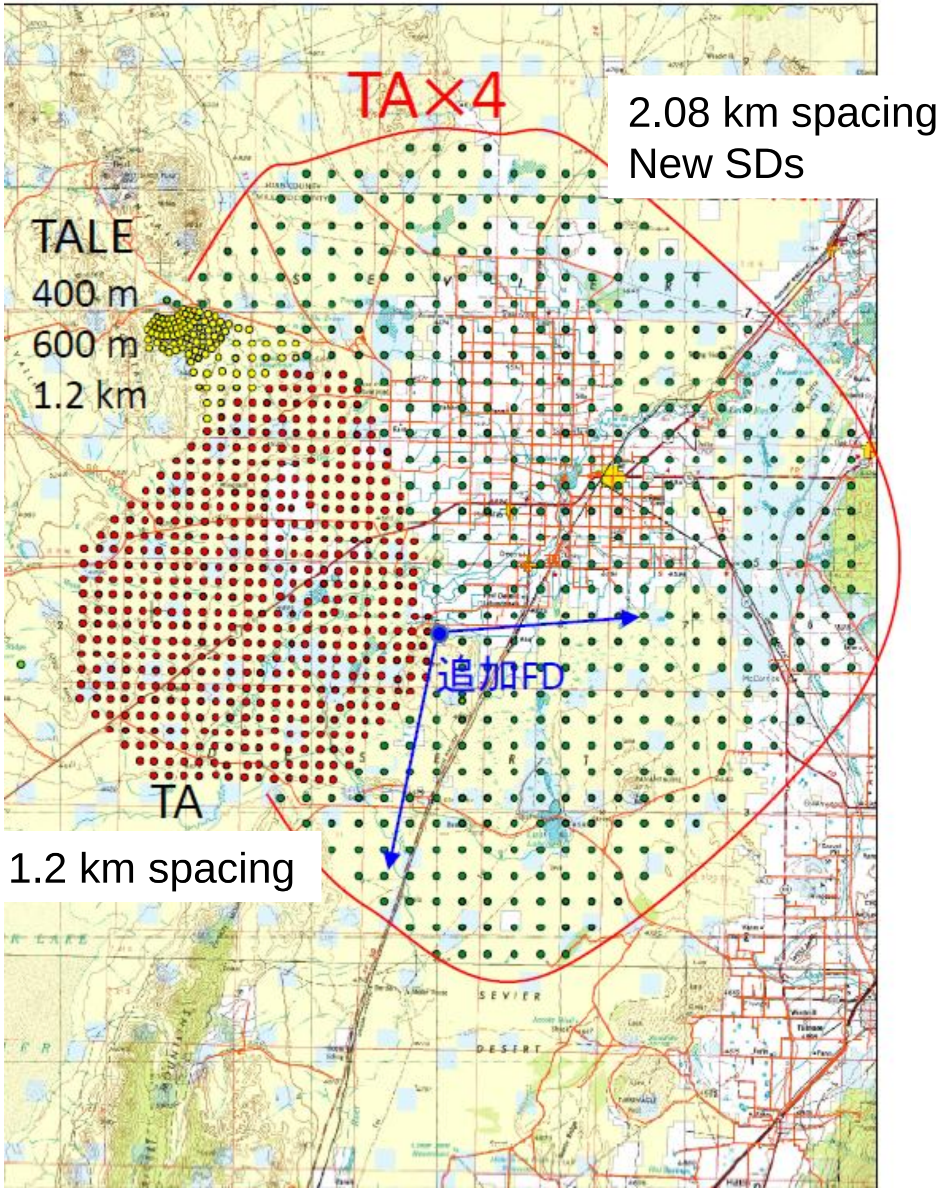
Re-use 10 FDs of HiRes-II. (USA)

2 years construction

3 years observation

Anisotropy Search:

〜3σ 5 years TA → 〜5σ 20 years TA



2.08 km spacing
New SDs

1.2 km spacing